Effects of frequency shifts on vowel category judgments

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Introduction

- Listeners can understand frequency-shifted speech across a wide frequency range (Fu & Shannon, 1999).
- We hypothesize that this ability can be explained in terms of listeners' sensitivity to statistical variation across talkers in natural speech.
- The aims of the present study were:
 1. To study the effects of frequency shifts on the identification of a vowel continuum
 2. To test the predictions of a model of vowel perception that incorporates measures of fundamental frequency (F_0) and formant frequencies (FF) associated with size differences in larynx and vocal tract across talkers

Co-variation of formant frequencies and F_0 in natural speech

Mean $\log FF$: Geometric mean of formant frequencies: F_1, F_2, F_3
>3000 vowels in hVd words (Assmann & Katz, 2000)

Pattern recognition model

- Hillenbrand & Nearey (1999) dual-target model
- Parameters: duration, mean F_0 , and F_1 , F_2 , F_3 sampled at 20% and 80% points
- Training data: 3000+ vowels spoken by 10 men, 10 women and 30 children from the N. Texas region (Assmann & Katz, 2000)
- *A posteriori* probabilities derived from linear discriminant analysis for each stimulus vowel

Frequency shifts and vowel identification

- In a previous study (Assmann, Nearey & Scott, 2002) we confirmed that upward shifts in F_0 or formant frequencies (FF) resulted in lower vowel identification accuracy.
- However, *combining* upward shifts in F_0 with upward shifts in FF led to *improved* identification accuracy.
- This finding that vowel identification accuracy is higher with coordinated shifts in F_0 and FF is well predicted by the model of vowel identification outlined below, and supports the idea that listeners are sensitive to the pattern of co-variation of F_0 and FF in natural speech.

Vowel Identification Accuracy

(Assmann, Nearey, and Scott, ICSLP 2002).

Vowel Identification Experiment

- The present study examined the effects of frequency shifts on vowel category boundaries along a continuum from /bɪt/ to /bɛt/
- Natural recordings of /bɪt/ and /bɛt/ from an adult female talker were analyzed and resynthesized using the STRAIGHT vocoder, and upward and downward frequency shifts were introduced

STRAIGHT vocoder

- High-quality vocoder, STRAIGHT (Kawahara, 1997) used to generate 9-step continuum from /bɪt/ to /bɛt/.
 - High-resolution analysis of time-varying spectrum envelope
 - Wavelet-based instantaneous frequency F_0 extraction
 - Spectrum envelope (**FF**) scaling
 - Fundamental frequency (**F₀**) scaling

Synthesis of Stimuli

- The 9-step continuum from “bit” to “bet” was generated by interpolation of the time-varying spectrum envelope on the dB scale.
- Here we show a sampled spectrum envelope for each step on the baseline continuum, taken from the vowel midpoint (average of 20 frames; 1-ms frame rate). The “bet” endpoint is shown in red; “bit” is shown in blue.

Scale Factors

Scale Factors

F ₀ scale factors		
0.5	1.0	1.25

FF scale factors		
0.75	1.0	1.33

- Baseline voice (scale factors: F₀=1.0, FF=1.0) is adult female
- Downward shifts tend to produce male-like voices; upward shifts heard as child-like voices

Method

- 810 syllables (9-step continuum x 3 F_0 scale factors x 3 FF scale factors x 10 trials) presented diotically in double-walled sound booth
- 13 listeners identified the words “bit” or “bet” using a forced-choice two-button response box drawn on computer screen
- Stimuli blocked by voice type (F_0 x FF condition) and trials, but randomized within blocks

Observed Identification Functions

Observed Mean Boundaries

- Increasing the F_0 scale factor caused boundaries to shift towards the /bɪt/ endpoint
- Increasing the FF scale factor caused boundaries to shift towards the /bɛt/ endpoint
- Coordinated shifts (highlighted in yellow) show relatively little change

Model Implementation

- Formant frequencies and F_0 were measured from each of the 9 stimuli along the baseline continuum and were scaled up or down according to the condition
- The model generated *a posteriori* probabilities of /ɪ/ or /ɛ/ responses for each of the stimuli

Predicted Identification Functions

Predicted Mean Boundaries

- Increasing F_0 scale factor predicts boundaries shift towards /bɪt/ endpoint
- Increasing FF scale factor predicts boundaries shift towards /bɛt/ endpoint
- Vowel boundaries shift in predictable but opposite directions as a function of F_0 and FF

Observed and Predicted Boundaries

Conclusions

- Upward and downward shifts in F_0 and FF cause vowel category boundaries to shift in opposing directions, as predicted by the model.
- Coordinated shifts (raised F_0 and raised FF, or *vice versa*, highlighted in yellow) have little effect.

Conclusions

- Discrepancy between the model and the data at the extreme edges (F_0 : 1.25, FF: 0.75 and F_0 : 0.5, FF: 1.33)
- Possible reasons:
 - Ambiguous quality created by an apparent change in vocal tract size is inconsistent with the shift in pitch
 - Range effects (blocking may lead listeners to avoid all “bit” or all “bet” responses in a block)
 - Boundary estimates are less reliable when the identification functions lack clear crossovers

Follow-up experiment

- Smaller scale factor to avoid extreme edges
- Embed syllables in carrier sentence (and apply shifts to both carrier and test syllable) to eliminate trial-to-trial context effects
- Randomize order of conditions to eliminate possible range effects

References

1. Assmann PF, Katz WF. (2000) Time-varying spectral change in the vowels of children and adults. *J Acoust Soc Am.* 108(4): 1856-1866.
2. Assmann, P.F., Nearey, T.M., and Scott, J.M. (2002) Modeling the perception of frequency-shifted vowels. *Proceedings of the 7th International Conference on Spoken Language Processing*, pp. 425-428.
3. Fu, Q-J. & Shannon, R.V. (1999). Recognition of spectrally degraded and frequency-shifted vowels in acoustic and electric hearing. *J Acoust Soc Am.* 105: 1889-1900.
4. Hillenbrand JM, Nearey TM. (1999) Identification of resynthesized /hVd/ utterances: effects of formant contour. *J Acoust Soc Am.* 105(6): 3509-3523.
5. Kawahara, H. (1997) Speech representation and transformation using adaptive interpolation of weighted spectrum: vocoder revisited. *Proc. IEEE Int. Conf. on Acoustics, Speech & Signal Processing (ICASSP '97)*, vol.2, pp.1303-1306.